OPTIMIZATION OF THE TOOL PARAMETERS IN ULTRASONIC

VIBRATION ASSISTED DRILLING BY TAGUCHI METHOD

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ABSTRACT

Today the world is developing very fast and through to achieve the goal of precisely machined jobs and instruments. Be it, defense instruments or surgical tools there is a need of precisely machined tools in each and every field. For fulfilling this growing demand of market, the advanced machining technologies are developed and improvised since last few decades. These advanced machining techniques involves Electric Discharge Machining, Electro-Chemical Machining, Ultrasonic Machining etc. This can be combined with conventional turning, drilling or milling processes to obtain better results in terms of surface finish, material removal rate and. tool wear rate. In this research paper an attempt is made to optimize the tool wear parameters and surface roughness parameters by varying the machining parameters like power rating, abrasive grit size, slurry material, and also tool material in ultra-sonic drilling process. Also, the process is optimized by Taguchi method and graphical interpretation of Tool wear rate (TWR) and SR (surface roughness) is done against variables by ANOVA (analysis of variance).Finally ,the impact of each parameter is plotted in bar chart separately for Tool Wear Rate and Surface Roughness using raw data and S/N ratio analysis data to determine the error in each case.

KEYWORDS: ANOVA, Surface Roughness, Taguchi ,Tool Wear Rate, Ultra-Sonic Drilling

INTRODUCTION

The Current research aims to gain the technical concept of UAD process [1]. It has been observed that the horn is a vital part of UAD process and the natural frequency and amplitude of vibration not only depends on the shape of the horn but also depends on the material of the horn [2].FEM (finite element analysis) is used for designing and development of Horn [3].Drilling of stainless steel work piece material by Ultrasonic Assisted Drilling process is done, and results are analyzed in terms of tool wear rate and surface finish [4]. Tool parameters are optimized by Taguchi design[5].The experiments were conducted to access the influence of a specific parameter viz. Tool material, Abrasive, Grit size,& Power Rating on the machining characteristics of interest (TWR, Surface roughness) by using 'one factor at a time approach'[6].

METHODOLOGY OF EXPERIMENTATION

In this experiment we have used taguchi based single quality optimization for determining the robust, efficient, and optimum values of our need. Taguchi's method is one of the most widely used optimization method by scholars and researchers for its simplicity, efficiency and robustness. Here we have used it achieve our goal to determine the optimum tool parameters in ultrasonic drilling. We have also used Analysis of Variance (ANOVA) to determine the significant and insignificant factors, and also there level of significance in both Tool Wear Rate and Surface Roughness. Also, S/N

ratios are used to quantitatively determine the response variation and their comparison. There are generally three S/N inspection index viz. Lower the Better, Higher the Better, and Nominal the Better. This are explained briefly below:

Lower the Better Type Variation

$$\partial = -10log_{10}(\frac{1}{n}\sum_{i=1}^{n} y_i^2) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ …. (i)}$$

Example is tool wear rate variation; here we use LB type S/N ratio for conversion of raw data, as tool wear rate should be as minimal as possible. Unit of S/N is db.

Higher the Better Type Variation

Here the maximum value of S/N ratio is taken and is favorable for experimental conditions where we need a maximum output value for example in Material removal rate , we generally use Higher the better type variation.=

$$\partial = -10log_{10}(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (ii)}$$

Nominal-the-Best Type Variation

The quality characteristic in the nominal-the-best type variation is continuous and non-negative, and also the target value is non zero as it gives a finite value. For these types of variations, as the mean tends to zero the variance also tends to become zero. A scaling factor is used as an adjustment factor to shift the mean closer to the target for these variations. The objective function that is to be maximized is expressed as:

$$\partial = 10log_{10}(\frac{\mu^2}{\sigma^2}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (iii)}$$

$$\mu = \frac{1}{n}\sum_1^n y_i^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (iv)}$$

$$\sigma = \frac{1}{(n-1)\sum_1^n (y_i-\mu)^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (v)}$$

In this experiment we have used lower-the-better type S/N ratio to transform the raw data, as our motive is to minimize the response.

The values of DOF, MS, SS', F and P as shown in ANOVA tables are calculated using MacAnova Software.

3. EXPERIMENTAL RESULTS & DISCUSSIONS

The following experimental results are based on single optimization quality test of Taguchi Method, where the discrete variables are arranged and tested against robust design for determining the effect on both tool wear rate and surface roughness. The considerable machining parameters are abrasive slurry concentration, abrasive grit size, power rating, and abrasive slurry type. For abrasive slurry concentration parameter, two levels were taken and for other three parameters three levels were taken. Here the results for S/N and raw data are determined in an orthogonal array of 18 groups which are tabulated in Table 1 and Table 2 for Tool Wear rate and Surface Roughness respectively.

Table 1: Results of Tool Wear Rate

Trial No.	Tool Material	Abrasive	Grit Size	Power Rating	Twr (Mm3/Min)	S/N Ratio	Mean
1	HCS	Alumina	220	100	0.44	7.11	0.44
2	HCS	SiC	320	250	0.65	3.72	0.65
3	HCS	B$_4$C	500	400	0.89	1	0.89
4	HSS	Alumina	220	250	0.49	6.15	0.49
5	HSS	SiC	320	400	1.01	-0.13	1.01
6	HSS	B$_4$C	500	100	0.33	9.51	0.33
7	Ti	Alumina	320	100	0.19	14.12	0.19
8	Ti	SiC	500	250	0.34	9.31	0.34
9	Ti	B$_4$C	220	400	1.14	-1.16	1.14
10	Ti Alloy	Alumina	500	400	0.19	14.26	0.19
11	Ti Alloy	SiC	220	100	0.15	16.39	0.15
12	Ti Alloy	B$_4$C	320	250	0.41	7.72	0.41
13	Carbide	Alumina	320	400	0.69	3.23	0.69
14	Carbide	SiC	500	100	0.57	4.88	0.57
15	Carbide	B$_4$C	220	250	1.18	-1.42	1.18
16	HCS	Alumina	500	250	0.2	13.89	0.2
17	HCS	SiC	220	400	1.58	-3.97	1.58
18	HCS	B$_4$C	320	100	0.36	8.79	0.36

Table 2: Results of Surface Roughness

Trial No.	Tool Material	Abrasive	Grit Size	Power Rating	Sr (Microns)	S/N Ratio	Mean
1	HCS	Alumina	220	100	0.92	0.74	0.92
2	HCS	SiC	320	250	1.16	-1.28	1.16
3	HCS	B$_4$C	500	400	0.66	3.56	0.66
4	HSS	Alumina	220	250	1.03	-0.35	1.03
5	HSS	SiC	320	400	1.23	-1.83	1.23
6	HSS	B$_4$C	500	100	0.59	4.56	0.59
7	Ti	Alumina	320	100	0.63	3.83	0.63
8	Ti	SiC	500	250	0.83	1.56	0.83
9	Ti	B$_4$C	220	400	2.1	-6.47	2.1
10	Ti Alloy	Alumina	500	400	0.66	3.51	0.66
11	Ti Alloy	SiC	220	100	0.67	3.38	0.67
12	Ti Alloy	B$_4$C	320	250	0.84	1.54	0.84
13	Carbide	Alumina	320	400	1.04	-0.38	1.04
14	Carbide	SiC	500	100	0.67	3.44	0.67
15	Carbide	B$_4$C	220	250	1.74	-4.8	1.74
16	HCS	Alumina	500	250	0.75	2.42	0.75
17	HCS	SiC	220	400	2.24	-6.99	2.24
18	HCS	B$_4$C	320	100	0.81	1.82	0.81

Table 3: Actor Effects on S/N

Factor	Level	TWR S/N	R$_a$ S/N
(A) Tool Material			
	A1)HCS	5.09	0.04
	A2)HSS	5.18	0.79
	A3)Titanium	7.42	-0.35
	A4)Titanium alloy	12.79	2.81
	A5)Cemented Carbide	2.23	-0.58

Table 3: Contd.,			
(B)Abrasive Type			
	B1)Alumina	9.79	1.63
	B2)Silicon Carbide	5.03	-0.29
	B3)Boron Carbide	4.07	0.04
(C)Slurry Grit Size			
	C1)220	3.85	-2.42
	C2)320	6.24	0.62
	C3)500	8.81	3.17
(D)Power Rating			
	D1)100W (20%)	10.13	2.97
	D2)250W (50%)	6.56	-0.15
	D3)400W (80%)	2.20	-1.44

Table 4: Factor Effects on Average Response

Factor	Level	TWR S/N	R_a S/N
(A) Tool Material			
	A1)HCS	0.69	1.09
	A2)HSS	0.61	0.95
	A3)Titanium	0.56	1.19
	A4)Titanium alloy	0.25	0.72
	A5)Cemented Carbide	0.81	1.15
(B)Abrasive Type			
	B1)Alumina	0.37	0.84
	B2)Silicon Carbide	0.72	1.13
	B3)Boron Carbide	0.72	1.12
(C)Slurry Grit Size			
	C1)220	0.83	1.45
	C2)320	0.55	0.95
	C3)500	0.42	0.69
(D)Power Rating			
	D1)100W (20%)	0.34	0.72
	D2)250W (50%)	0.54	1.06
	D3)400W(80%)	0.92	1.32

Effects of Process parameters on Tool wear rate and surface roughness are shown on average response graph and S/N ratio graph as shown below from the data inferred from table 3 and table 4.
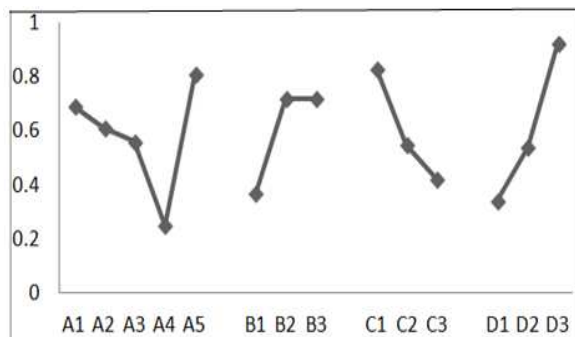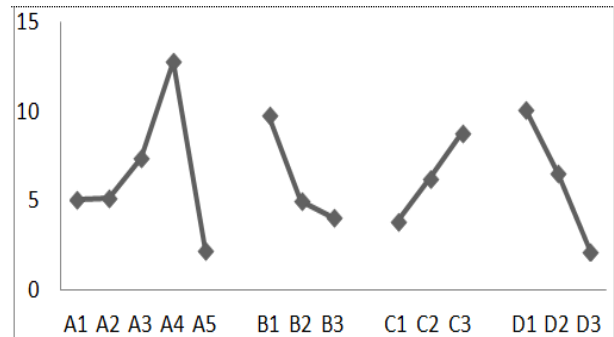

Figure 1: TWR Raw Data Average Response Graph

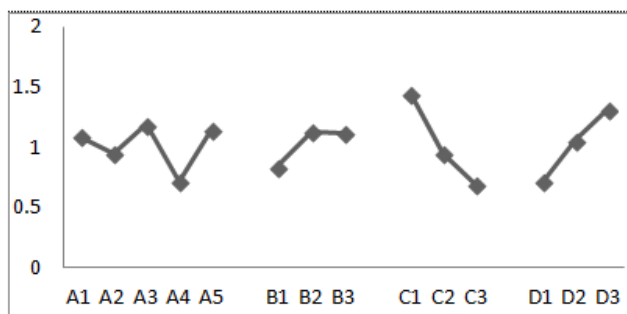

Figure 2: TWR S/N Ratio Response Graph

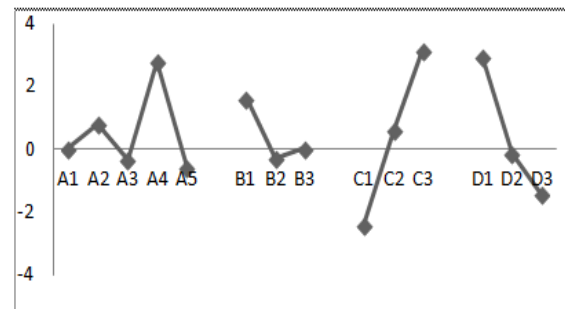**Figure 3: Surface Roughness Raw Data**
Average Response

Figure 4: Surface Roughness S/N Ratio Response
Graph *A1,A2, A3, A4,A5,B1,B2,B3,C1,
C2,C3, D1,D2,& D3 are factor levels

Analysis of Variance for Tool Wear Rate and Surface Roughness

The S/N ratio is obtained using Taguchi's methodology. ANOVA (analysis of variance) is done to obtain percentage contribution of process parameters. Thus, information about how significant the effect of each controlled parameter is on the quality characteristic of interest can be obtained. The total variation in the ANOVA (general linear model) for raw data and S/N data have been performed to identify the significant parameters and to quantify their effect on the performance characteristic. The ANOVA based on the raw data signifies the factors, which affect the average response rather than reducing variation the result is the sum of variation due to various controlled factors and their interactions and variation due to experimental error. The minute analysis of response curve associated with S/N ratio based raw data is done to obtain the best or optimal level of process parameters. ANOVA results for TWR(S/N Data), TWR (raw data), Surface roughness(S/N Data) & Surface roughness (raw data) are tabulated in tables 5,6,7,8.

Table 5: ANOVA Results for TWR(S/N Data)

Source	DF	Seq SS	Adj. SS	Adj.MS	F	(%)P
Tool	4	192.581	192.581	48.145	6.38*	31.0
Abrasive	2	112.107	112.107	56.053	7.42*	18.0
Grit Size	2	74.129	74.129	37.065	4.91*	12.0
Power Rating	2	188.656	188.656	94.328	12.49*	30.5
Error	7	52.864	52.864	7.552		8.5
Total	17	620.336				
$F_{tab}=F(4,43)=2.60F(2,43)=3.21$ Order of Significance 1. Power Rating 2.Abrasive material 3. Tool 4.Grit Size						

Table 6: ANOVA Results for TWR (Raw Data)

Source	DF	Seq SS	Adj. SS	Adj.MS	F	(%)P
Tool	4	1.65	1.65	0.41	21.5*	19.6
Abrasive	2	1.48	1.48	0.74	38.4*	17.4
Grit Size	2	1.57	1.57	0.78	40.8*	18.7
Power Rating	2	3.07	3.07	1.53	79.7*	36.3
Error	43	0.82	0.82	0.019		8.0
Total	53	8.59				
$F_{tab}=F(4,43)=2.60F(2,43)=3.21$ Order of Significance 1.Power Rating2.Grit Size 3. Abrasive type 4.Tool						

Table 7: ANOVA Results for Surface Roughness(S/N Data)

Source	DF	Seq SS	Adj. SS	Adj.MS	F	(%)P
Tool	4	23.147	23.147	5.787	1.81	10.8
Abrasive	2	12.728	12.728	6.364	1.99	6.0
Grit Size	2	93.927	93.927	46.963	14.68*	44.0
Power Rating	2	61.516	61.516	30.758	9.62*	28.8
Error	7	22.392	22.392	30.199		10.4
Total	17	13.710				
$F_{tab}=F(4,43)=2.60 F(2,43)=3.21$						
Order of Significance 1. Grit size 2.Power Rating ;Other factors Insignificant						

Table 8: ANOVA Results for Surface Roughness (Raw Data)

Source	DF	Seq SS	Adj. SS	Adj.MS	F	(%)P
Tool	4	1.31	1.31	0.33	6.42**	10.3
Abrasive	2	0.99	0.99	0.50	9.72**	7.8
Grit Size	2	5.30	5.30	2.65	51.80**	41.5
Power Rating	2	3.33	3.33	1.67	32.64**	26.2
Error	43	1.40	1.40	0.037		14.2
Total	53	12.30				
$F_{tab}=F(4,43)=2.60 F(2,43)=3.21$						
Order of Significance 1. Grit size 2.Power Rating 3.Abrasive type 4.Tool						

FINAL CONCLUSIONS AND DISCUSSIONS

Effect on Tool Wear Rate

The tool wear rate (TWR) increases proportionately with an increase in power rating of Ultrasonic Drilling Machine, the increase rate is sluggish between 100W to 250W.But, with increase in power rating between 250W to 400W, there is a sharp increase in TWR. This is probably due to increase in momentum of abrasive particles with which they strike the work surface and tool surface. Hence, between 250W to 400W, there is rapid rupturing of tool material which increases Tool Wear Rate(TWR).

With respect to the S/N response, the values of S/N ratio for different factor levels have been found to be highest for those factor levels that correspond to highest average response for TWR. Hence, it can be concluded from this discussion that ***"input parameters settings of ultrasonic power rating at 100W, with Titanium alloy tool and Aluminium oxide slurry with a fine grit size of 500 have given the optimum results for TWR; when stainless steel was machined"***.

For average response, all the factors except power rating are almost equally significant for their contribution to the variation in TWR. For S/N response, tool material has been found to be having highest percent contribution (31.0%) followed by power rating (30.5%) whereas slurry grit size is least significant (12.0%).

Effect on Surface Roughness

Similar to Tool Wear Rate, Surface Roughness (SR) also increases proportionately with an increase in power rating of Ultrasonic Drilling Machine, the increase rate is sluggish between power rating 100W to 250W.But as power rating increases from 250W to 400W, the Surface Roughness (SR) increases. This can be explained on the similar basis to MRR or TWR. Large chunks of work piece material are removed by high momentum abrasive particles and the surface roughness increases.

It has also been observed that for a particular tool material, surface roughness obtained attains the highest value at that particular grit size-power level combination which corresponds to largest value of MRR.In other words; surface roughness is optimum at the points of maximum Material removal rate similar to the case of Tool Wear Rate.

The contribution factor in terms of percentage for slurry grit size has been found to be the highest among all the factors (42.5%) whereas power rating comes next (27.2%). Remaining factors can be termed as relatively insignificant for surface roughness. The S/N results indicate that slurry grit size has highest percent contribution (44.0%) followed by power rating (28.8%) for their effect on surface quality. The other two factors (tool material and abrasive type) have been found to be insignificant as far as S/N response is concerned. Hence, it can be concluded that "*While machining Stainless Steel with USM, input parameter settings of ultrasonic power rating at 100 W, with titanium alloy tool and aluminium oxide slurry with a fine grit size of 500 have given the optimum results for surface quality.*

A careful visual observation of the tool surface after machining reveals formation of a dish in the centre of the tool face. The hardness of the tool increases by work hardening, thereby, penetration of the abrasive grains into the tool decreases resulting in higher MRR from the periphery of the work zone and consequently a convex surface is formed in the work piece . This causes plastic deformation of the centre of the tool face. The tendency of the dish formation has been observed to be most severe with high carbon steel tool. High speed steel and titanium alloys are comparatively tougher materials, hence the dish formation for these tools is lesser pronounced as compared to the other tools.

The pie charts below shows percent contribution of different factors in variation of Tool Wear Rate and Surface Roughness.
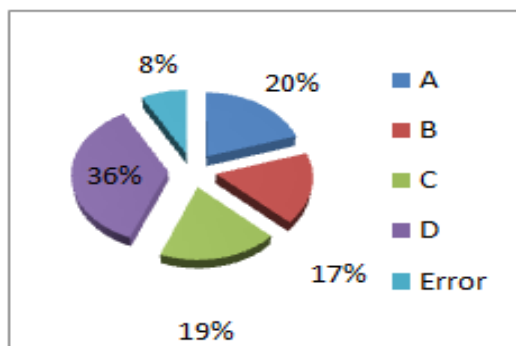

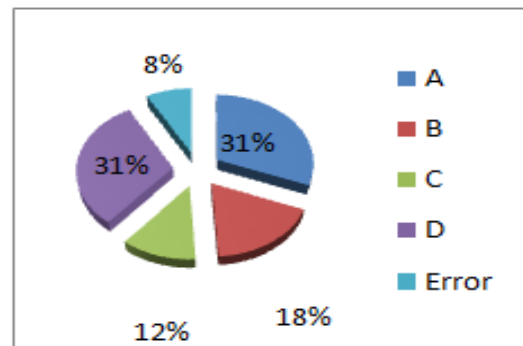**Figure 5: Percent Contribution in Variation of Tool Wear Rate (Raw Data**

Figure 6: Percent Contribution in Variation the of Tool Wear Rate (S/N data)
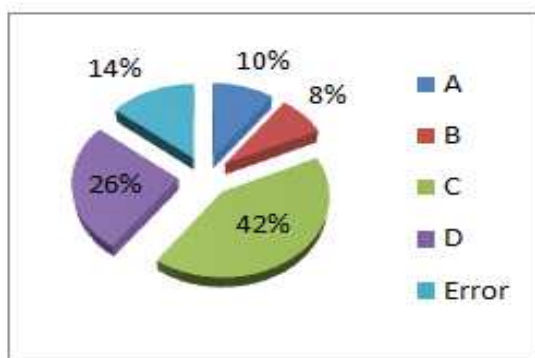

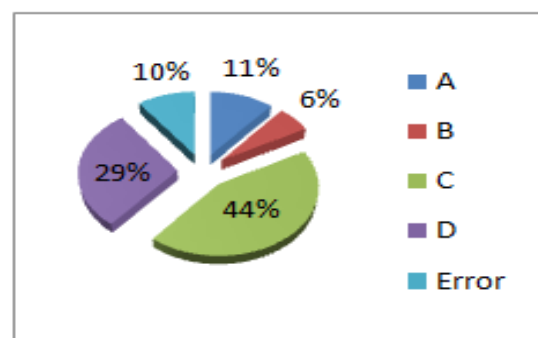**Figure7: Percent contribution in Variation of of Surface Roughness(Raw Data)**

Figure 8: Percent Contribution in Variation of Surface Roughness(S/N Data)

REFERENCES

1. J. Pujana –" Analysis of ultrasonic-assisted drilling of Ti6Al4V" , *International Journal of Machine Tools & Manufacture,*Volume 49,May 2009 ,pp-500-508

2. Thomas P.N.H. – "Experiments and Simulations on ultrasonically assisted drilling", *Journal of Sound and Vibration, Volume 308, 4 December 2007, pp-815-830*

3. Astashev V.K,-"Effect of ultrasonic vibrations of a single point tool on the process of cutting", *J. Mach. Manuf. Reliability, 5 (3), 1992,*

4. Astashev V. K. and Babitsky V. I. –"Ultrasonic cutting as a nonlinear (vibro-impact) process", *Ultrasonics, 36 (1998):*

5. Nanu A.S. "Study on Ultrasonic stepped Horn geometry design & FEM Simulation" *Nonconventional Technologies Review 2011, pp-25-30*

6. P.L. Guzzo , "A Comparative Study on Ultrasonic Machining of Hard & Brittle Materials"*Journal of Brazilian Society of Mechanical Sciences & Engineering, Volume 26, March 2004, pp-500*

7. Farukh Makhdum , "Cutting Forces in ultrasonically assisted drilling of carbon fibre reinforced plastics" *Journal of Physics:Conference Series,*Volume 382, November 1,2012

8. Chandra Nath , "Effect of machining parameters in ultrasonic vibration cutting" *International Journal of Machine Tools & Manufacture, 25 January 2008,pp-18-26*

9. Shrikrushna B. Bhosale- "Effect of Process parameter on MRR , TWR and surface topography in USM of alumina-zirconia ceramic composite", *Ceramics International, Volume40,Issue8, September 2014, pp-12831–12836*

10. H.Hocheng- "Online tool wear monitoring during USM using tool resonance frequency".*Journal of Materials Processing Technology, Volume 123, Issue 1,10 April 2002, pp-80-84.*

11. J.Akbari- "Investigating the effects of vibration method on ultrasonic-assisted drilling of Al/SiCp metal Matrix composites". *Robotics and Computer-Integrated Manufacturing, Volume 30, Issue 3, June 2014, Pages 344-350*

12. Vaibhav A. Phadnis- "A finite element model of Ultrasonically assisted drilling carbon/epoxy composites." *Procedia CIRP, Volume 8, 2013, Pages 141-146*

13. V.I. Babitsky- "Vibration excitation and energy transfer during ultrasonically assisted drilling".*Journal of Sound and Vibration, Volume 308, Issues 3–5, 4 December 2007, Pages 805-814*

14. Simon G.F. Chang- "Burr Size reduction in drilling by ultrasonic assistance". *Robotics and Computer-Integrated Manufacturing, Volume 21, Issues 4–5, August–October 2005, Pages 442-450*

15. Z.Zhang- "Finite element modelling of a micro drill and experiments on high speed ultrasonically assisted micro drilling." *Journal of Sound and Vibration, Volume 330, Issue 10, 9 May 2011, Pages 2124-2137*

16. Inderdeep Singh- "Conventional and unconventional hole making in metal matrix composites." *Machining and machine-tools, 2013, Pages 169-193*

17. Dahu Zhu- "Tool wear characteristics in machining of nickel based superalloys."*International Journal of Machine Tools and Manufacture, Volume 64, January 2013, Pages 60-77*

18. Rupinder Singh-"Ultrasonic Machining of Titanium & its alloys: A review" *Journal of Materials Processing Technology, Volume 173, Issue 2, 10 April 2006, Pages 125-135*

19. G.Bradfield- "Ultrasonic Transducers"

20. *Simon S.F. Chang – "Thrust Force model for vibration assisted drilling of aluminium 6061-T6."International Journal of Machine Tools and Manufacture, Volume 49, Issue 14, November 2009, Pages 1070-1076*

21. *Palanisamy- "Study of parametric optimization of burr formation in step drilling of eutectic Al-Si alloy –Gr composites."*

22. *KWH Seah – "Design of tool holders for Ultrasonic machining using FEM." Journal of Materials Processing Technology, Volume 37, Issues 1–4, February 1993, Pages 801-816*

23. *Devin j.-"Ultrasonically assisted metal removal", SAMPLE Quarterly, 10 (1979):*

24. *Nath C. and Rahman M.- "Effect of machining parameters in ultrasonic vibration cutting", International Journal of Machine Tools and Manufacture, Vol. 48 (2008)*

25. *M.Adithan-"Tool Wear Studies in Ultrasonic Drilling" (1974)*

26. *M.Adithan &V C Venkatesh- "Parameter influence on tool wear in ultrasonic drilling"(1975)*

27. *M. Adithan- "Abrasive Wear in ultrasonic drilling" (1988)*